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Cress

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(54) **PRECHAMBER SPARKPLUG HAVING ELECTRODES LOCATED FOR INHIBITING FLAME KERNEL QUENCHING**

(71) Applicant: **Caterpillar Inc.**, Peoria, IL (US)

(72) Inventor: **James Jay Cress**, West Lafayette, IN (US)

(73) Assignee: **Caterpillar Inc.**, Peoria, IL (US)

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H01T 13/46 (2006.01)
H01T 13/16 (2006.01)
F02B 19/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H01T 13/467*** (2013.01); ***F02B 19/08*** (2013.01); ***H01T 13/16*** (2013.01); ***H01T 13/46*** (2013.01)

(58) **Field of Classification Search**
CPC H01T 13/46–467; F02B 19/08
See application file for complete search history.

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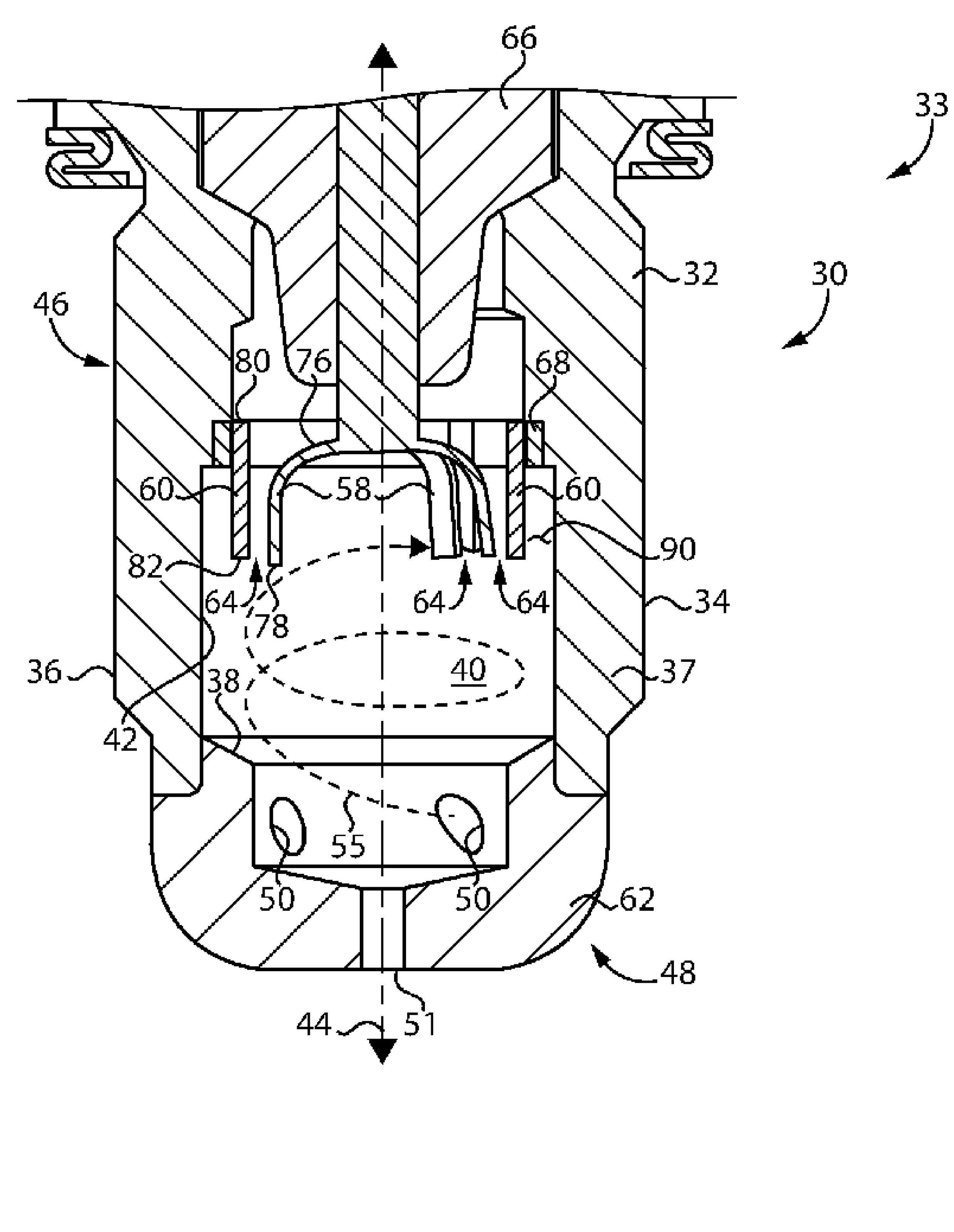
Primary Examiner — Mariceli Santiago
(74) *Attorney, Agent, or Firm* — Brannon Sowers & Cracraft

(57) **ABSTRACT**

A prechamber sparkplug includes a housing having a nozzle with a prechamber formed therein, and each of a first set and a second set of electrode prongs within the prechamber. The second set of electrode prongs downwardly depend from attachment points to the housing, and form, together with the first set of electrode prongs, spark gaps within the prechamber. Each of the anode-cathode pairs formed by the sets of electrode prongs is spaced radially inward a clearance distance from the prechamber wall to position the spark gaps in a flow of swirled gases. The flow of swirled gases displaces a flame kernel formed at the spark gaps to inhibit quenching.

15 Claims, 4 Drawing Sheets



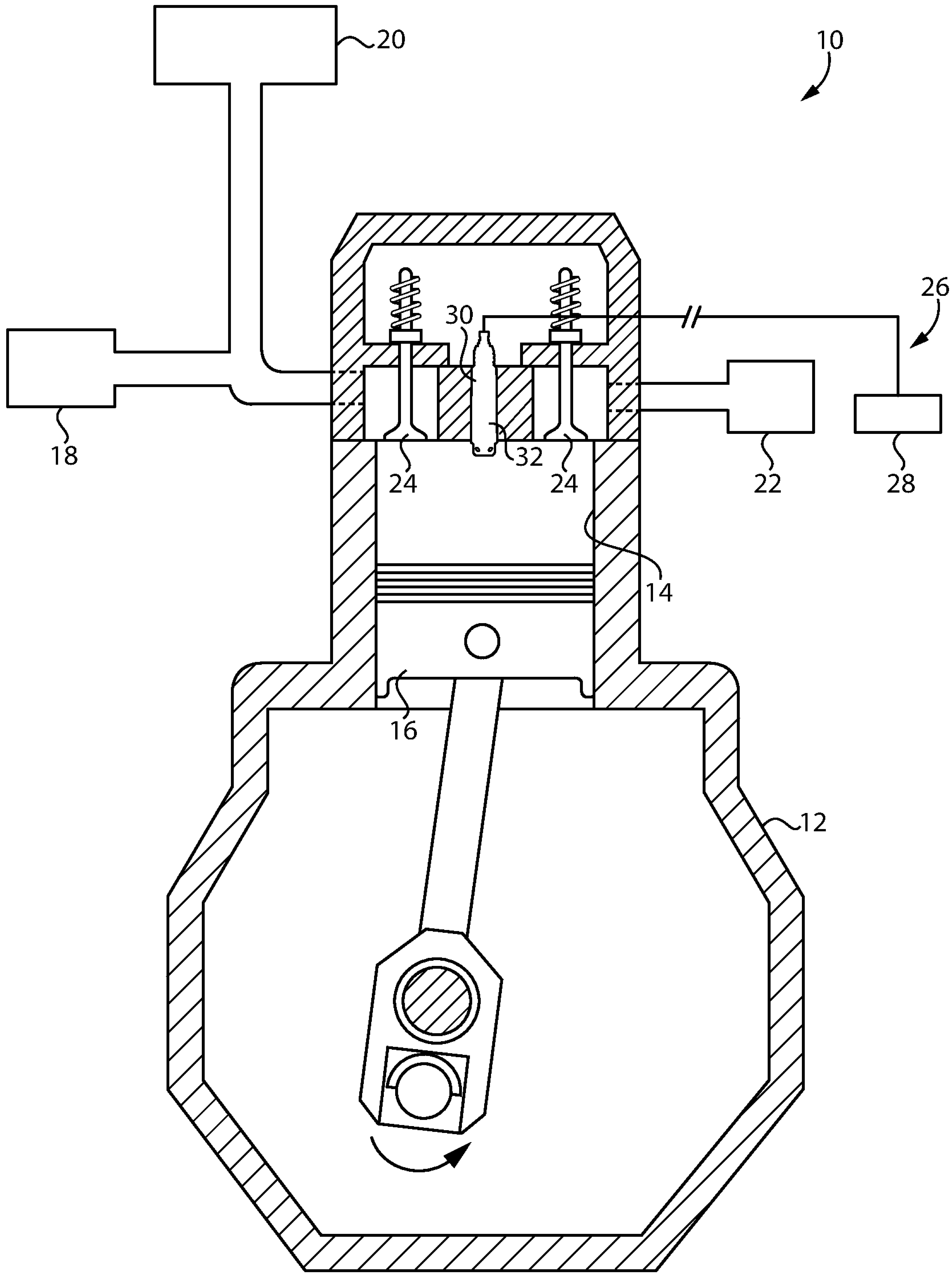


FIG. 1

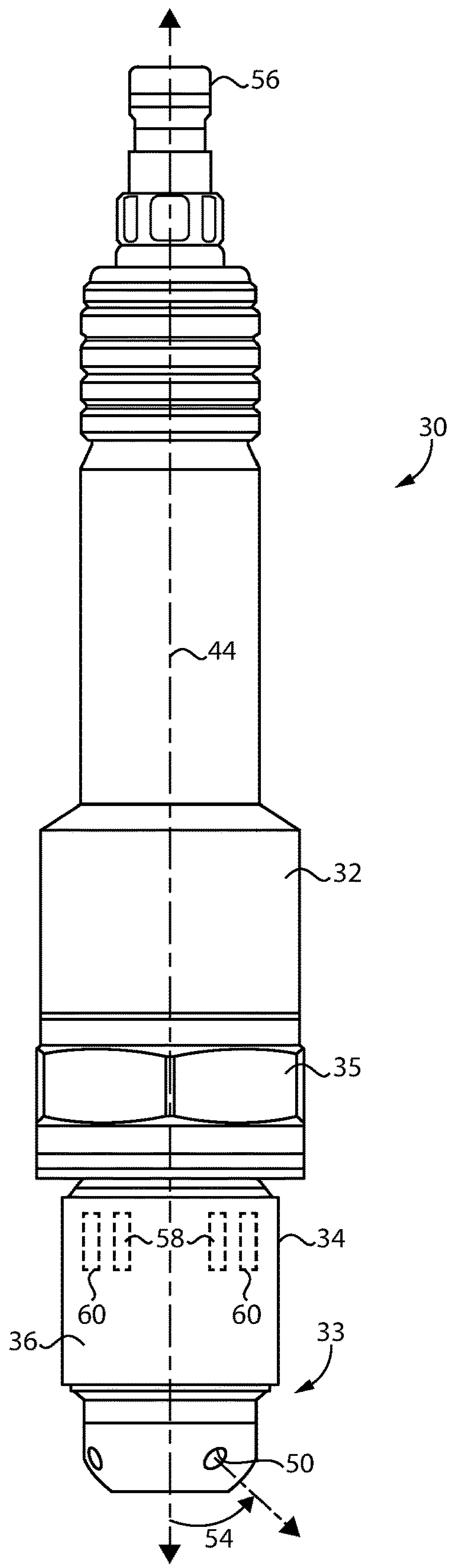


FIG. 2

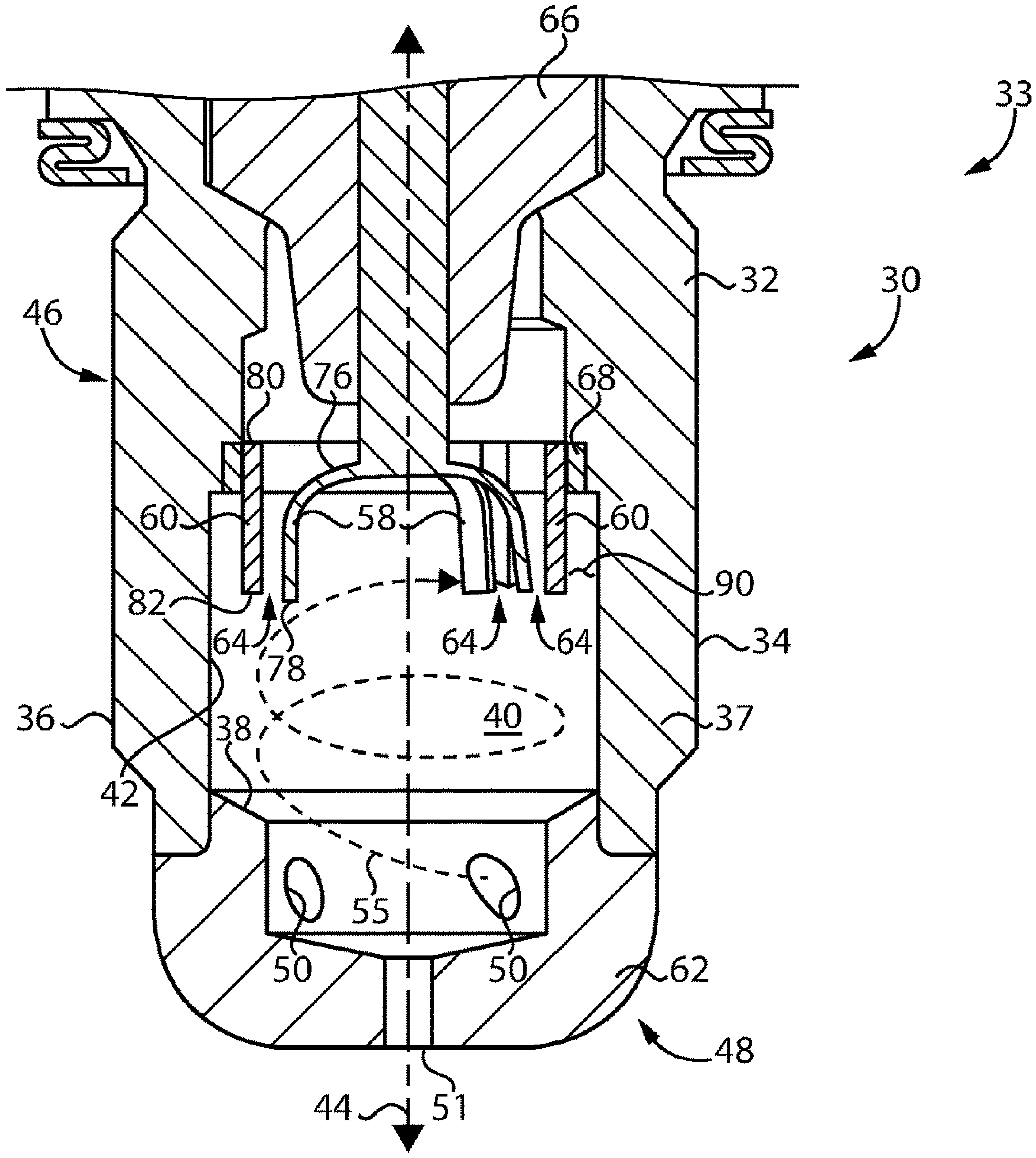

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FIG. 3

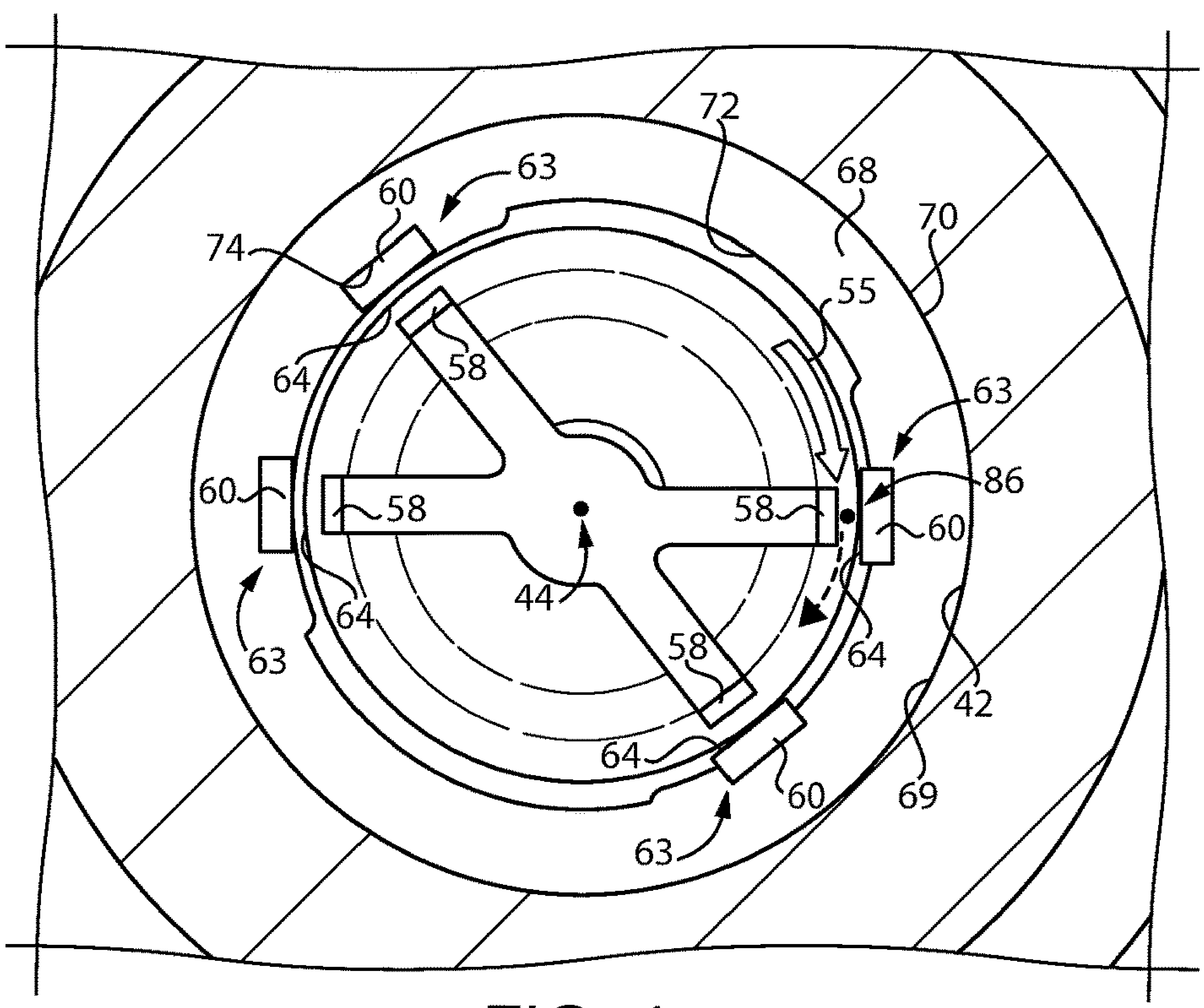
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FIG. 4

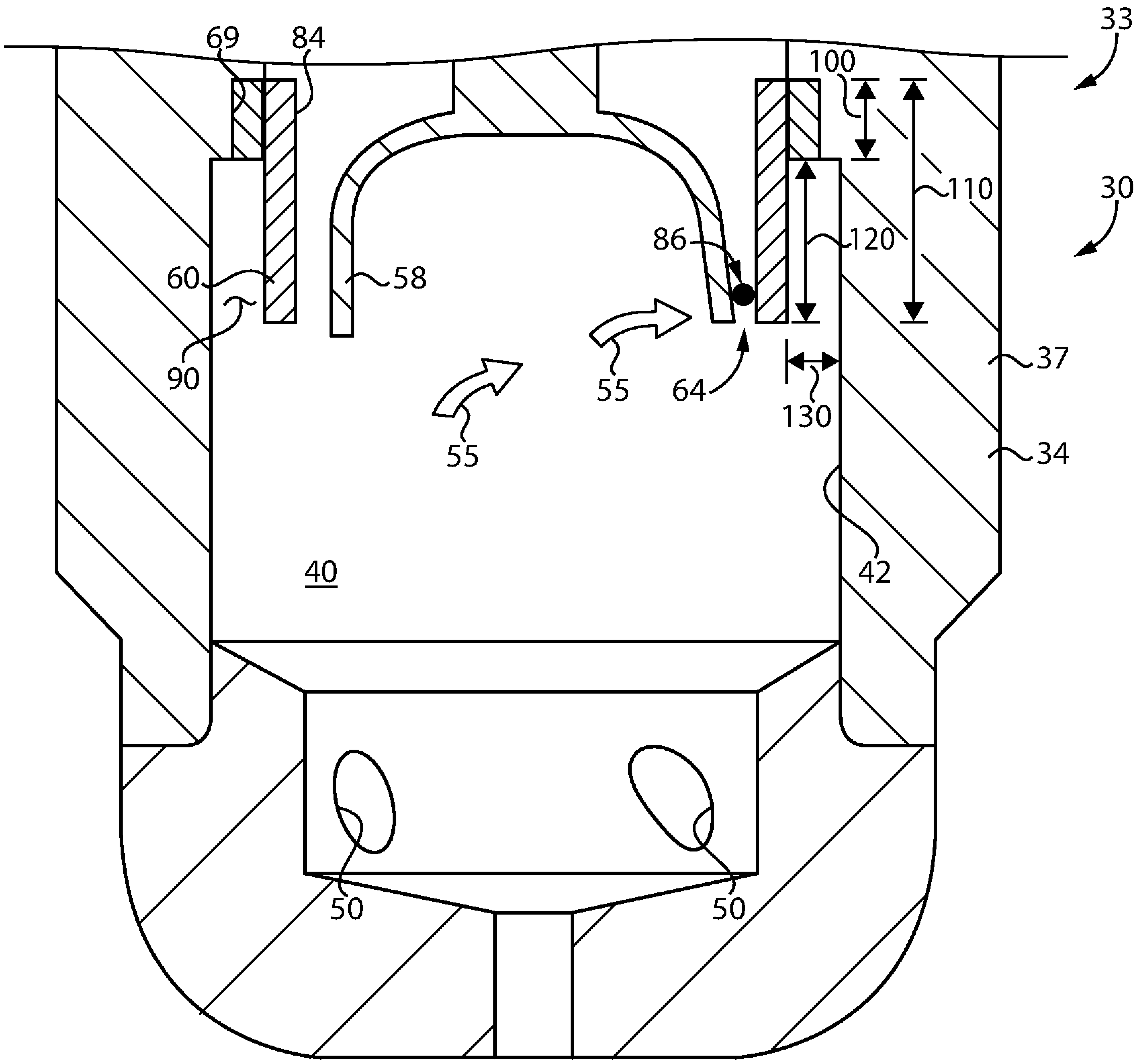

FIG. 5

PRECHAMBER SPARKPLUG HAVING ELECTRODES LOCATED FOR INHIBITING FLAME KERNEL QUENCHING

TECHNICAL FIELD

The present disclosure relates generally to a prechamber sparkplug, and more particularly to a prechamber sparkplug having electrodes located for inhibiting flame kernel quenching.

BACKGROUND

Internal combustion engines, including gasoline or natural gas spark-ignited engines, diesel compression ignition engines, dual fuel engines, and still others, generally operate by producing a controlled combustion reaction within a cylinder to drive a piston coupled with a rotatable crankshaft. Concerns as to emissions, as well as price and supply considerations, has led in recent years to increased interest in exploiting gaseous fuels such as natural gas. Certain gaseous fuels, including not only natural gas but also ethane, methane, landfill gas, biogas, mine gas, and various others can be combusted to produce relatively low levels of certain emissions and are often readily available even at remote locations. Advantages of gaseous fuel engines with respect to emissions tend to be most significant where the fuels are combusted in the engine at a stoichiometrically lean ratio of fuel to air, having an equivalence ratio less than 1. Conventional spark-ignition strategies can sometimes fail to reliably ignite lean mixtures, potentially leading to misfire or combustion stability problems. Employing a prechamber sparkplug can address some of these concerns by igniting a small, relatively confined charge of a lean fuel and air mixture in a prechamber using a spark, to produce a jet of hot combustion gases delivered to a main combustion chamber, resulting in a hotter, more uniform, and typically more robust combustion reaction as compared to other techniques such as traditional sparkplugs.

Stoichiometrically lean fuel mixtures may still fail to ignite in a prechamber, or even if some initial flame kernel can be produced the turbulent gas flow within the prechamber can extinguish the nascent flame. One strategy directed at preventing quenching of a newly formed flame kernel is set forth in U.S. Pat. No. 8,839,762 to Chiera et al. In Chiera, a multi-chamber igniter is structured to prevent quenching by enabling pushing a newly formed flame kernel to a separate chamber, and thereby isolating the flame kernel from gases in the prechamber. While Chiera et al. and other strategies may have certain applications, there is always room for improvement and alternative strategies in this field.

SUMMARY OF THE INVENTION

In one aspect, a prechamber sparkplug includes a housing having a nozzle with an outer surface, and an inner surface forming a prechamber having a prechamber wall extending circumferentially around a nozzle axis. The nozzle axis extends between an upper nozzle end, and a lower nozzle end forming at least one gas port extending from the inner surface to the outer surface and oriented at a swirl angle relative to the nozzle axis. The prechamber sparkplug further includes a first set of electrode prongs within the prechamber, and a second set of electrode prongs within the prechamber and downwardly depending from the housing, such that the second set of electrode prongs form, together with the first set of electrode prongs, anode-cathode pairs defining spark gaps within the prechamber. Each of the anode-cathode pairs is spaced radially inward a clearance distance from the prechamber wall to position the spark gaps in a flow of swirled gases from the at least one gas port.

In another aspect, a nozzle subassembly for a prechamber sparkplug includes a nozzle body having an outer surface, and an inner surface forming a prechamber having a prechamber wall extending circumferentially around a nozzle axis. The nozzle axis extends between an upper nozzle end, and a lower nozzle end forming at least one gas port extending from the inner surface to the outer surface and oriented at a swirl angle relative to the nozzle axis. The nozzle subassembly further includes a first set of electrode prongs including electrode tips within the prechamber, and a second set of electrode prongs each extending, in a path parallel to the nozzle axis, from a base end attached to the nozzle body to an electrode tip within the prechamber. The second set of electrode prongs are aligned with the first set of electrode prongs to form anode-cathode pairs defining spark gaps. Each of the anode-cathode pairs is spaced radially inward from the prechamber wall, such that a clearance extends between each anode-cathode pair and the prechamber wall and the spark gaps are positioned for impingement by a flow of swirled gases from the at least one gas port.

In still another aspect, a method of igniting a combustion charge in an engine includes conveying gases containing fuel and air through a port oriented at a swirl angle in a nozzle of a prechamber sparkplug such that a swirled flow of the gases is produced within a prechamber of the prechamber sparkplug. The method further includes producing a flame kernel at a spark gap of an anode-cathode pair having a spark gap location that is spaced a clearance distance radially inward of a prechamber wall. The method further includes displacing the flame kernel with the swirled flow of gases such that quenching of the flame kernel is inhibited, igniting the fuel and air within the prechamber by way of the displaced flame kernel, and discharging combustion gases produced from the ignition of the fuel and air from the port for igniting a main combustion charge in an engine.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partially sectioned diagrammatic view of an internal combustion engine system, according to one embodiment;

FIG. **2** is a diagrammatic view of a prechamber sparkplug, according to one embodiment;

FIG. **3** is a sectioned side diagrammatic view of a nozzle subassembly for a prechamber sparkplug, according to one embodiment;

FIG. **4** is an axial section view of a portion of a prechamber sparkplug, according to one embodiment; and

FIG. **5** is a sectioned side diagrammatic view of a nozzle subassembly for a prechamber sparkplug, according to one embodiment.

DETAILED DESCRIPTION

Referring to FIG. **1**, there is shown an internal combustion engine system **10** according to one embodiment. Internal combustion engine system **10** includes an engine housing **12** having a cylinder **14** formed therein, and a piston **16** movable within cylinder **14** between a top dead center position and a bottom dead center position in a generally conventional manner. Internal combustion engine system **10** (hereinafter "engine system **10**") also includes gas exchange valves **24** operable to open and close fluid connections between cylinder **14** and gas exchange conduits formed in engine housing **12**. Engine housing **12** may have any number of combustion cylinders formed therein, and in any suitable arrangement such as a V-pattern, an in-line pattern, or still another. Engine system **10** may be spark-ignited and structured to operate in a conventional four-cycle pattern upon a mixture of air and a gaseous fuel such as natural gas, methane, ethane, mine gas, landfill gas, biogas, blends of these, or still others. Engine system **10** could also operate upon a mixture of air and premixed gasoline, a mixture of gaseous fuel and a directly injected liquid fuel, or other combinations and configurations.

Engine system **10** includes an air inlet **18** structured to receive and supply a flow of air to cylinder **14**, and a fuel supply **20** which may include a gaseous fuel supply structured to provide a flow of fuel to an incoming flow of air for combustion. Additional equipment in the nature of a compressor, filters, fuel admission valves, vaporization and pressurization equipment for gaseous fuel stored in a liquid state, and still other apparatus may be provided in engine system **10** for supplying and conditioning air and fuel for combustion. The present disclosure is not limited in regards to the location and manner of supplying fuel to cylinder **14**. Exhaust produced by combustion of air and fuel in cylinder **14** can be conveyed to an exhaust system **22** for treatment and discharge in a generally conventional manner. Engine system **10** further includes an ignition system **26** having an electrical energy source **28** such as an ignition coil coupled with a prechamber sparkplug **30**.

Ignition system **26** could include other electrical apparatus for producing and/or controlling energizing of prechamber sparkplug **30**, including an electronic control unit or ECU. Prechamber sparkplug **30** includes a housing **32** and is mounted within engine housing **12** so as to produce hot jets of combustion gases that are advanced into cylinder **14** to ignite a main charge of fuel and air in cylinder **14** in a generally known manner. In the illustrated embodiment, piston **16** can be advanced in engine housing **12** toward a top dead center position to push a mixture of fuel and air into prechamber sparkplug **30**, such that all of the fuel and air in an ignition charge combusted in prechamber sparkplug **30** is thusly conveyed into prechamber sparkplug **30**. Engine system **10**, at least at times, may operate on a stoichiometrically lean charge of fuel and air, including an excess amount of air to an amount of fuel, however, the present disclosure is not thereby limited. As discussed above, ignition problems such as misfire can be observed in certain engine systems, notably engine systems operating on stoichiometrically lean mixtures of fuel and air. As will be further apparent from the following description, ignition system **26**, and including prechamber sparkplug **30**, may be uniquely configured for improved reliability in initiation of combustion of an ignition charge of fuel and air.

Referring also now to FIG. **2**, there are shown additional features of prechamber sparkplug **30**. Housing **32** may include a nozzle **34** having an outer surface **36**, and an inner surface discussed hereinafter, and a longitudinal nozzle axis **44**. An electrical connector **56**, for connecting to electrical energy source **28** is located at one end of prechamber sparkplug **30**, opposite to at least one gas port **50** that fluidly connect an internal prechamber in prechamber sparkplug **30** to cylinder **14**. The at least one gas port **50**, hereinafter referred to at times in the singular, is oriented at a swirl angle **54** relative to nozzle axis **44**. It should be appreciated that a swirl angle as contemplated herein means an angle defined by an orientation of gas port **50** that causes incoming gases into prechamber sparkplug **30** to travel in a circumferential swirling pattern about nozzle axis **44**. Gas port **50** may be oriented so as to have both an axially advancing component, up and down in the FIG. **2** illustration, and a radial component, left to right or in and out of the page in FIG. **2**, relative to nozzle axis **44**. Gas port **50** might be located on a chord of a circle centered on nozzle axis **44**, in an axial projection plane. A gas port located on a radius of a circle centered on nozzle axis **44** is not likely fairly considered oriented at a swirl angle. A gas port itself centered upon nozzle axis **44**, or parallel to nozzle axis **44**, is also not likely oriented at a swirl angle. Those skilled in the art will appreciate various orientations, including linear orientations, curvilinear orientations, and other geometric attributes of gas port **50** that can be employed in conjunction with the geometry of prechamber sparkplug **30** to induce a swirling flow of gases that are pushed through gas port **50** into prechamber sparkplug **30** in response to upward motion of piston **16** in cylinder **14**.

Referring also now to FIG. **3**, there are shown additional features of prechamber sparkplug **30** in a sectioned view. Housing **32** includes nozzle **34** as discussed above. Nozzle **34** may be part of a nozzle subassembly **33** having additional components as further discussed herein. Prechamber sparkplug **30** may be installed in engine housing **12** in any suitable manner, and will typically be installed by a threaded engagement to engage threads on prechamber sparkplug **30** with threads in engine housing **12**, such as by engaging a tool with a hex **35** as shown in FIG. **2** and rotating housing **32** relative to engine housing **12**. When installed, most or all of nozzle subassembly **33** will typically be positioned within cylinder **14**. As also noted above, nozzle **34** includes an outer surface **36**, and an inner surface **38** forming a prechamber **40** having a prechamber wall **42** extending circumferentially around nozzle axis **44**. Nozzle axis **44** extends between an upper nozzle end **46**, and a lower nozzle end **48** forming the at least one gas port **50**. The at least one gas port **50**, and in the illustrated embodiment a plurality of gas ports **50**, may be spaced circumferentially around nozzle axis **44**, and formed in a tip piece **62** of nozzle **34** in the illustrated embodiment. Gas port **50** extends from inner surface **38** to outer surface **36** and is oriented at swirl angle **54** relative to nozzle axis **44**, as illustrated in FIG. **2**. A swirl path is shown by way of example at numeral **55** in FIG. **3**, and it can be noted that gases conveyed into prechamber **40** by way of gas port **50** can circulate generally helically around nozzle axis **44** from lower nozzle end **48** toward upper nozzle end **46**, the significance of which will be further apparent from the following description. An axially extending gas port **51** is also shown in FIG. **3**, formed in tip piece **62**.

Prechamber sparkplug **30**, and nozzle subassembly **33**, further includes a first set of electrode prongs **58** within prechamber **40**, and a second set of electrode prongs **60** within prechamber **40**. Second set of electrode prongs **60** downwardly depend from attachment points with housing **32**. Second set of electrode prongs **60** may further be understood each to extend in an axially advancing path parallel to nozzle axis **44**. Referring also to FIG. **4**, second set of electrode prongs **60** form, together with first set of electrode prongs **58**, anode-cathode pairs **63** defining spark gaps **64** within prechamber **40**. In the illustrated embodiment a total of four anode-cathode pairs **63** are shown although in other instances more than four pairs, or a total of one, might be used. The paths along which second set of electrode prongs **60** extend may further be understood as parallel to nozzle axis **44** from a base end **80** attached to housing **32**, including for example a nozzle body **37**, to an electrode tip **82** positioned within prechamber **40**. Nozzle body **37** forms a part of housing **32**. First set of electrode prongs **58** may each be understood to extend from a base end **76** to an electrode tip **78** within prechamber **40**.

Second set of electrode prongs **60** are aligned with first set of electrode prongs **58** to form anode-cathode pairs **63**. Each of anode-cathode pairs **63** is spaced radially inwards, a clearance distance from prechamber wall **42**, such that a clearance **90** extends radially between each anode-cathode pair **63** and prechamber wall **42**. Clearance **90** may be fully circumferential of all of anode-cathode pairs **63** such that an unobstructed flow path for swirled gases extends axially along prechamber wall **42**, and circumferentially around prechamber **40**. This arrangement positions spark gaps **64** in a flow of swirled gases from port **50**, including for direct impingement by the flow of swirled gases from port **50**. As further discussed herein, this positioning of spark gaps **64** can assist in displacing of a flame kernel such that quenching of the flame kernel is inhibited, and ignition reliability and robustness improved.

As can also be seen from the Figures, each of spark gaps **64** extends radially between electrode prongs **58** and **60** forming the respective anode-cathode pair **63**. First set of electrode prongs **58** may be positioned radially inward of second set of electrode prongs **60** and electrically connected to electrical terminal **56**. Also in the illustrated embodiment, first set of electrode prongs **58** are supported in an insulator **66** coupled to housing **32**. Those skilled in the art will recognize first set of electrode prongs **58** as being similar to certain known electrode prong configurations, extending in a curvilinear path from the respective base end **76** to the respective electrode tip **78**. Each of second set of electrode prongs **60** may extend in a linear path from the respective base end **80** to respective electrode tip **82**. It will thus be appreciated that the curvilinear paths of first set of electrode prongs **58** enables first set of electrode prongs **58** to each approach one of second set of electrode prongs **60** to form spark gaps **64** generally at locations of closest approach. Within each anode-cathode pair **63** electrode prongs **58** may be the cathode, and electrode prongs **60** the anode, although a reversed polarity could in certain instances be employed. Electrode prongs **58** are thus electrically connected to electrical terminal **56**, and electrode prongs **60** are electrically connected to housing **32**.

Further alternatives could employ different shapes or paths for the respective electrode sets **58** and **60**. For example, embodiments are contemplated where electrodes **60** have curved paths and electrodes **58** have linear paths. It will also be appreciated that, while each anode-cathode pair **63** will typically be structured such that electrode tips **78** and **82** are in circumferential alignment and spark gaps **64** extend between them according to only a radial aspect, in some instances a degree of circumferential offset could be employed such that spark gaps **64** have both a radial aspect and a circumferential aspect. In still other instances, spark gaps **64** might have only a circumferential aspect, and no radial aspect. In any event, spark gaps **64** are positioned in prechamber **40** such that the swirled flow of gases therein can assist in displacing a flame kernel away from the spark gap and also away from surfaces that can cause quenching as further discussed herein.

Referring also now to FIG. **5**, housing **32** may further include an insert **68** positioned within a bore **69** in housing **32**, and attached such as by welding. Insert **68** is thus part of nozzle body **37**. Insert **68**, which may be annular, extends circumferentially around nozzle axis **44** and forms an electrode opening **84** for first set of electrode prongs **58**. Second set of electrode prongs **60** may be supported in insert **68** and electrically connected to insert **68**, in turn electrically connecting electrode prongs **60** to housing **32**. Each of electrode prongs **60** may be positioned within a slot **74** formed in an inner diameter surface **72** of insert **68**. An outer diameter surface **70** of insert **68** may contact housing **32** within bore **69**. Insert **68** and electrode prongs **60** could all be formed as one piece in certain embodiments. Moreover, electrode prongs **60**, insert **68**, and nozzle body **37** could all be formed as a single uniform piece, although forming insert **68** of an insert material, and second set of electrodes **60** of an electrode material different from the insert material provides a practical implementation strategy. The insert material could be steel or another iron-based alloy, and the electrode material could be nickel, iridium, platinum, or another suitable electrode material. Nozzle body **37** could be formed of a nozzle body material, the same as or different from the insert material, with electrodes **58** and electrodes **60** being formed of an electrode material different from the nozzle body material. Electrodes **58** and electrodes **60** are both consumable and will tend to erode during service, typically and desirably at approximately the same rates.

Also shown in FIG. **5** are certain geometric and proportional attributes of nozzle subassembly **33**. As shown in FIG. **5**, each one of second set of electrodes **60** has an exposed electrode length **120**, within prechamber **40**. Exposed electrode length **120** is greater than a size **130** of clearance **90** in at least some embodiments. Insert **68** may further have an insert axial thickness **100**. Insert axial thickness may be equal to a heat transference length **100** that each of second set of electrodes **58** has with insert **68**, and thus with housing **32**. An electrode full axial length is shown at **110** and may be from two times to four times heat transference length **100**. Put differently, a length of contact between each of electrodes **60** and housing **32**, in the illustrated case insert **68**, may be from about 25% to about 50% of a full axial length of each of second set of electrodes **60**. A length of electrode exposed within housing **32** can affect a temperature of the electrode that will tend to be observed during service. Temperatures that are too low can impact the lean capability of a prechamber sparkplug, whereas temperatures too high can create other problems. According to the present disclosure, a length of electrode that is exposed to hot gases within prechamber **40**, relative to a length of electrode that is attached to and in heat transference contact with housing **32**, can affect a temperature of the subject electrode that will tend to be observed during service. By making the electrode length exposed to hot combustion gases relatively larger as compared to the heat transference length with the housing, a temperature of the electrode may be relatively higher. Where the exposed electrode length as compared to the heat transference length is relatively less, the temperature of the electrode that can be expected to be observed may be relatively lower. It has been determined that the described range provides practical boundaries for tuning electrode temperature based upon engine operating and combustion conditions that are expected to be experienced during service.

INDUSTRIAL APPLICABILITY

Referring to the drawings generally, as discussed above piston **16** is reciprocated within engine housing **12** typically in a four-cycle pattern to compress fuel and air, expand in response to combustion of fuel and air, reciprocate back upward to expel exhaust gases, and then return downward to draw in a fresh charge of fuel and air for another cycle.

During a compression stroke of piston **16**, gases containing fuel and air will be conveyed through port **50**, oriented at swirl angle **54**, such that a swirled flow of gases is produced within prechamber **40**. At an appropriate timing, ignition system **26** may be energized or operated to energize electrodes **58**, producing an electrical spark at one of spark gaps **64**, that produces a flame kernel **86**. Flame kernel **86**, produced at a spark gap **64** of typically one of anode-cathode pairs **63** at any one time, will be spaced a clearance distance radially inward of prechamber wall **42**.

As the swirled flow of gases advances around prechamber **40** the nascent flame kernel **86** will tend to be displaced from the one of spark gaps **64**, and carried along in the swirled flow of gases. Each of FIGS. **4** and **5** depicts flame kernel **86** as it might appear about to be displaced by the swirled flow of gases. Displacing spark kernel **86** rapidly and carrying flame kernel **86** along with the swirled fuel and air, away from prechamber wall **42** and other structures, is believed to prevent quenching of flame kernel **86** by avoiding structures and materials that have a cooling effect, and assist in achieving improved ignition robustness and combustion stability in prechamber **40**. The combustion initiated within prechamber **40** will then create a rapid pressure and temperature rise that produces jets of hot gases containing combustion products and potentially actively combusting gases from port **50** into cylinder **14** to initiate combustion of the main charge of fuel and air therein.

The present description is for illustrative purposes only, and should not be construed to narrow the breadth of the present disclosure in any way. Thus, those skilled in the art will appreciate that various modifications might be made to the presently disclosed embodiments without departing from the full and fair scope and spirit of the present disclosure. Other aspects, features and advantages will be apparent upon an examination of the attached drawings and appended claims. As used herein, the articles "a" and "an" are intended to include one or more items, and may be used interchangeably with "one or more." Where only one item is intended, the term "one" or similar language is used. Also, as used herein, the terms "has," "have," "having," or the like are intended to be open-ended terms. Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise.

What is claimed is:

1. A prechamber sparkplug comprising:

a housing including a nozzle having an outer surface, and an inner surface forming a prechamber having a prechamber wall extending circumferentially around a nozzle axis;

the nozzle axis extending between an upper nozzle end, and a lower nozzle end forming at least one gas port extending from the inner surface to the outer surface and oriented at a swirl angle relative to the nozzle axis;

a first set of electrode prongs within the prechamber;

a second set of electrode prongs within the prechamber and downwardly depending from the housing, such that the second set of electrode prongs form, together with the first set of electrode prongs, anode-cathode pairs defining spark gaps within the prechamber; and

each of the anode-cathode pairs is spaced radially inward a clearance distance from the prechamber wall to position the spark gaps in a flow of swirled gases from the at least one gas port.

2. The prechamber sparkplug of claim **1** wherein each of the spark gaps extends radially between the electrode prongs forming the respective anode-cathode pair.

3. The prechamber sparkplug of claim **2** further comprising an electrical terminal, and wherein the first set of electrode prongs are radially inward of the second set of electrode prongs and electrically connected to the electrical terminal.

4. The prechamber sparkplug of claim **3** wherein the first set of electrode prongs are supported in an insulator coupled to the housing, and wherein the housing includes an insert and the second set of electrode prongs are supported in the insert and electrically connected to the insert.

5. The prechamber sparkplug of claim **4** wherein the insert is annular and extends circumferentially around the nozzle axis and forms an electrode opening for the first set of electrode prongs.

6. The prechamber sparkplug of claim **5** wherein the insert is formed of an insert material, and the second set of electrode prongs are formed of an electrode material different from the insert material.

7. The prechamber sparkplug of claim **4** wherein the insert has an insert axial thickness, and each one of the second set of electrode prongs has a full electrode axial length that is from **2** times to **4** times the insert axial thickness.

8. A nozzle subassembly for a prechamber sparkplug comprising:

a nozzle body having an outer surface, and an inner surface forming a prechamber having a prechamber wall extending circumferentially around a nozzle axis;

the nozzle axis extending between an upper nozzle end, and a lower nozzle end forming at least one gas port extending from the inner surface to the outer surface and oriented at a swirl angle relative to the nozzle axis;

a first set of electrode prongs including electrode tips within the prechamber;

a second set of electrode prongs each extending, in a path parallel to the nozzle axis, from a base end attached to the nozzle body to an electrode tip within the prechamber;

the second set of electrode prongs are aligned with the first set of electrode prongs to form anode-cathode pairs defining spark gaps; and

each of the anode-cathode pairs is spaced radially inward from the prechamber wall, such that a clearance extends between each anode-cathode pair and the prechamber wall and the spark gaps are positioned for impingement by a flow of swirled gases from the at least one gas port.

9. The nozzle subassembly of claim **8** wherein each of the first set of electrode prongs extends in a curvilinear path from a base end to the respective electrode tip, and each of the second set of electrode prongs extends in a linear path from the respective base end to the respective electrode tip.

10. The nozzle subassembly of claim **8** wherein each one of the second set of electrode prongs has an exposed electrode length, within the prechamber, greater than a size of the clearance.

11. The nozzle subassembly of claim **8** wherein the second set of electrode prongs each have a heat transference length with the housing, and full electrode axial length that is from 2 times to 4 times the heat transference length.

12. The nozzle subassembly of claim **8** wherein the first set of electrode prongs are located radially inward of the second set of electrode prongs and supported in an insulator coupled to the nozzle body.

13. The nozzle subassembly of claim **12** wherein the nozzle body includes an insert and the second set of electrode prongs are supported in the insert.

14. The nozzle subassembly of claim **13** wherein the insert includes an inner diameter surface forming an electrode opening for the first set of electrode prongs, and the second set of electrode prongs are attached to the inner diameter surface and spaced circumferentially around the electrode opening.

15. The nozzle subassembly of claim **8** wherein the nozzle body is formed of a nozzle body material and each of the first set of electrode prongs is formed of an electrode material different from the nozzle body material.

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